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APPENDICIES

Appendix A Calculation of Facial Surface Area Equivalent Diameter and Specific Surface Area

1. Calculation of Facial Surface Equivalent Diameter

From the picture from Scanning Scanning Electron Microscope (SEM)

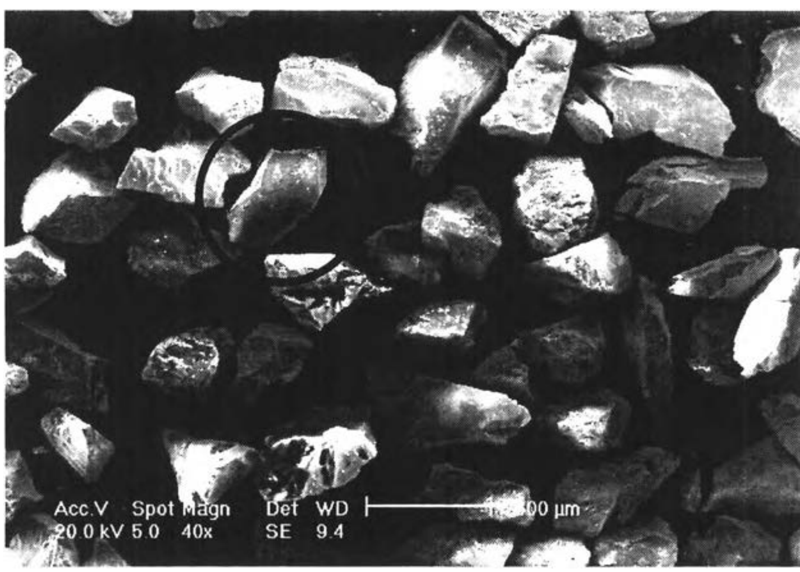

Figure A.1 Analcime particles in the size of 0.212-0.300 mm

Using ImageJ software program, the facial surface area of the labeled particle can be obtained.

Facial surface area (Area) = 183404.50 μm^2

The facial surface area equivalent diameter (D_e) is defined as:

$$D_e = \sqrt{\frac{Area}{\pi}} \quad (A.1)$$

Therefore, the analcime particle with facial surface area of 183404.50 μm^2 has D_e equal to 241.6184 μm or approximately 0.242 mm.

2. Calculation of Specific Surface Area

For analcime in the sieve size 0.71-1.18 mm,

Average actual diameter (D) = 0.6875 mm

Specific gravity of analcime (ρ) = 2.26 x 10^6 g/mm^3

Assuming analcime particle is spherical,

Volume per particle (V) $= \frac{4}{3}\pi r^3 = \frac{\pi D^3}{6}$ = 0.17 mm^3

Mass per particle (M) $= \rho V$ = 3.84 g

Surface area per particle $= 4\pi r^2 = \pi D^2$ = 1.48 mm^2

Specific surface area = Surface area per particle / Mass per particle

= 3.87 x 10^6 mm^2/g

3. Calculation of ρ_s

Amount of analcime (W) = 1.00615 g

Density of analcime = 2.255 g/cm^3 = 2255 g/dm^3

Volume of analcime = 4.462 x 10^{-4} dm^3

Volume of citric acid solution = 0.15 dm^3

Total volume in system (V) = 15.0446 x 10-2 dm^3

$$\rho_s = \frac{W}{V} \quad \text{(A.2)}$$

Therefore, ρ_s of 1.00615 g analcime in the size of 0.212-0.300 mm is equal to 6.69 g analcime/ dm^3 total volume in system.

Appendix B Kinetics Analysis of Analcime Dissolution in Batch Experiments

Experimental Conditions:

Weight of analcime	= 1.0081 g
Size of analcime	= 0.212-0.300 mm
External surface area	= 1.60 x 10^3 dm^2/g
ρ_s	= 6.69 g analcime/dm^3 of total volume
Citric acid concentration	= 0.1M
Volume of citric acid used	= 150 mL
Temperature	= 25°C
Stirring rate	= 250 rpm

The calibration curve of Al for Atomic absorption spectroscopy (AAS) is shown in Figure B.1.

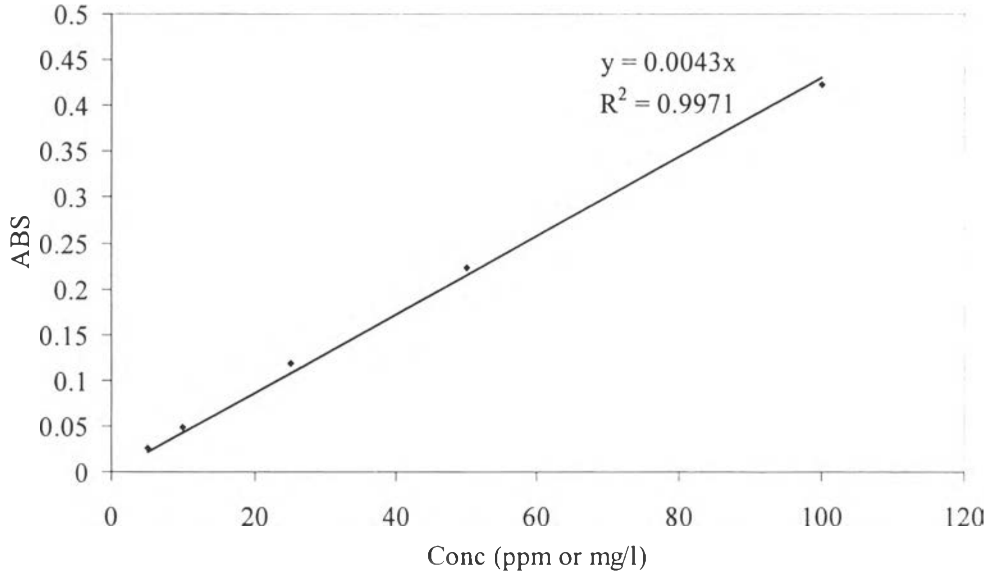

Figure B.1 Calibration curve of Al

Table B.1 Informatin of Al element in sample solution from dissolution experiment in slurry reactor (analcime initial particle size of 0.212-0.300 mm, 0.1M citric acid, 250 rpm, 25°C)

Time (hr)	ABS	Conc. Of Al		Volume of solution in reactor (l)	Al/intial analcime x10^3 (mole/g)	Al/surface area of intial analcime x10^7 (mole/dm^2)
		mg/l	mmole/dm^3			
0.000	-	-	-	0.150	-	-
0.017	0.004	3.72	0.1379	0.146	0.0206	0.129
0.033	0.005	4.65	0.1724	0.142	0.0258	0.161
0.050	0.007	6.51	0.2414	0.138	0.0361	0.226
0.067	0.009	8.37	0.3103	0.134	0.0464	0.290
0.083	0.011	10.23	0.3793	0.130	0.0567	0.354
0.100	0.013	12.09	0.4482	0.126	0.0670	0.419
0.117	0.015	13.95	0.5172	0.122	0.0773	0.483
0.133	0.016	14.88	0.5517	0.118	0.0825	0.516
0.150	0.019	17.67	0.6551	0.114	0.0980	0.612

To calculate the initial dissolution rate of Al, plot graph between Al concentration (mole/g and mole/dm^2) and time (hr)

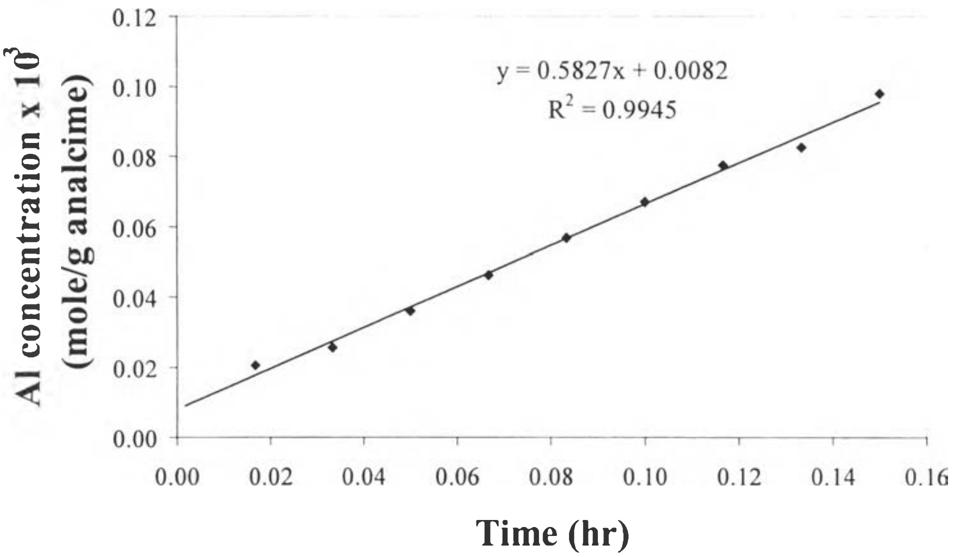

Figure B.2 Al concentration per g of initial analcime as a function of time

Initial dissolution rate of aluminum = 0.5827 mole Al/g.hr

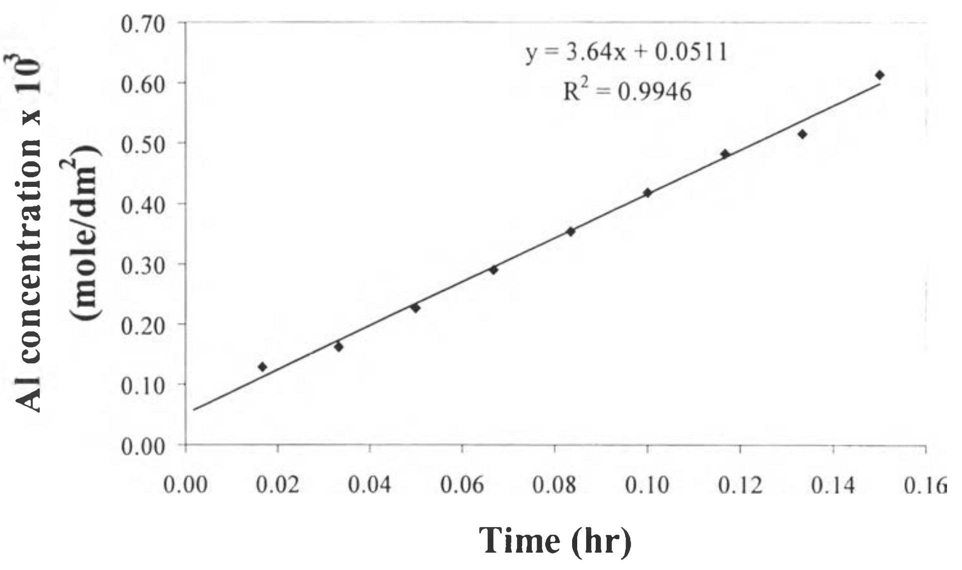

Figure B.3 Al concentration per external surface area of initial analcime as a function of time

Initial dissolution rate of aluminum = 3.64 mole/dm^2.hr

For Si and Na, initial dissolution rates can be obtained in the same manner.

Appendix C Calculation Method for Deprotonation Curve of Citric Acid

1. Equilibrium Acid Constant

The equilibrium acid constant is defined in terms of the activity of product species divided by reactant species as shown below:

Consider the following reaction:

$$HA + H_2O \leftrightarrow A^- + H_3O^+$$

The equilibrium acid constant is expressed as:

$$Ka = \frac{a_{H_3O^+} a_{A^-}}{a_{HA}} \tag{C.1}$$

where 'a' denotes the activities of the hydrated species

Rearranging Eq. (C.1):

$$a_{H_3O^+} = \frac{(Ka)(a_{HA})}{a_{A^-}} \tag{C.2}$$

Taking the logarithms both sides of Eq. (C.2):

$$-\log a_{H_3O^+} = -\log\left[\frac{(Ka)(a_{HA})}{a_{A^-}}\right] \tag{C.3}$$

Rearranging Eq. (C.3):

$$-\log a_{H_3O^+} = -\left[\log Ka - \log\frac{a_{A^-}}{a_{HA}}\right] \tag{C.4}$$

where $pH = -\log a_{H_3O^+}$ and $pKa = -\log Ka$

Therefore, Eq. (C.4) becomes:

$$pH = pKa + \log\left[\frac{a_{A^-}}{a_{HA}}\right] \quad (C.5)$$

or

$$pH = pKa + \log\left[\frac{a_{basicspecies}}{a_{acidicspecies}}\right] \quad (C.6)$$

2. Activity

The activity is defined as:

$$a_i = C_i f_i \quad (C.7)$$

where C_i = Molar concentration (M)

f_i = Activity coefficient

Substituting Eq. (C.7) into Eq. (C.1)

$$Ka = \frac{(C_{H_3O^+} f_{H_3O^+})(C_{A^-} f_{A^-})}{(C_{HA} f_{HA})} \quad (C.8)$$

Rearranging Eq. (C.8):

$$Ka = \frac{C_{H_3O^+} C_{A^-}}{C_{HA}} \cdot \frac{f_{H_3O^+} f_{A^-}}{f_{HA}} \quad (C.9)$$

$$Ka = Ka'\frac{f_{H_3O^+} \cdot f_A}{f_{HA}} \qquad (C.10)$$

where $Ka' = \dfrac{C_{H_3O^+} \cdot C_A}{C_{HA}}$

Rearranging Eq. (C.10):

$$Ka' = Ka\frac{f_{HA}}{f_{H_3O^+} \cdot f_A} = f(T, f_i) \qquad (C.11)$$

The Eq. (C.6) is normally used in terms of molar concentration unit (M), therefore the Eq. (C.6) is expressed as:

$$pH = pKa' + \log\left[\frac{C_{basicspecies}}{C_{acidicspecies}}\right] \qquad (C.12)$$

In general, the equilibrium reaction of acid is shown as:

$$H_nA^{X-} \leftrightarrow H_{n-1}A^{(X+1)-} + H^+ \qquad (C.13)$$

From Eq. (C.13), Eq. (C.12) becomes:

$$pH = pKa' + \log\left[\frac{C_{H_{n-1}A^{(X+1)-}}}{C_{H_nA^{X-}}}\right] \qquad (C.14)$$

From Eq. (11), it is illustrated that Ka' is a function of temperature (T) and activity coefficient (f_i), nevertheless the activity coefficient is also depended upon the ionic strength (I) as shown by the Debye-Huckel equation. The Debye-Huckel equation for dilute solution can be expressed as:

$$\log f_i = -\frac{AZ^2 I^{0.5}}{1 + I^{0.5}} + 0.1Z^2 I \qquad \text{(C.15)}$$

where f_i = Activity coefficient

I = Ionic strength (M)

Z = Charge

A = Temperature-dependent constant (at 25oC: A = 0.512)

Coupling Eq. (C.15) with Eq. (C.14), Eq. (C.14) becomes:

$$pH = pKa - \frac{(2x+1)AI^{0.5}}{(1+I^{0.5})} + 0.1(2x+1)I + \log\left[\frac{C_{H_{n-1}A^{(x+1)-}}}{C_{H_n A^{x-}}}\right] \qquad \text{(C.16)}$$

where

$$pKa' = pKa - \frac{(2x+1)AI^{0.5}}{(1+I^{0.5})} + 0.1(2x+1)I \qquad \text{(C.17)}$$

3. Calculation Method for Deprotonation Curves

Citric acid is a polyprotic acid which dissociates in three steps depended upon the number of ionizable protons containing in the molecules as shown below:

$C_6H_8O_7 \leftrightarrow C_6H_7O_7^- + H^+$ $\qquad pKa_1 = 3.128$

$C_6H_7O_7^- \leftrightarrow C_6H_6O_7^{2-} + H^+$ $\qquad pKa_2 = 4.761$

$C_6H_6O_7^{2-} \leftrightarrow C_6H_5O_7^{3-} + H^+$ $\qquad pKa_3 = 6.396$

The dissociation of citric acid can be expressed in terms of three equilibrium acid constants as shown by the following equations:

$$Ka_1 = \frac{[C_6H_7O_7^-]\cdot[H^+]}{[C_6H_8O_7]} \qquad \text{(C.18)}$$

$$Ka_2 = \frac{[C_6H_6O_7^{2-}]\cdot[H^+]}{[C_6H_7O_7^-]} \quad (C.19)$$

$$Ka_2 = \frac{[C_6H_5O_7^{3-}]\cdot[H^+]}{[C_6H_6O_7^{2-}]} \quad (C.20)$$

The total citric acid concentration is the summation of all citric acid species:

$$Citricacid_{Total} = [C_6H_5O_7^{3-}] + [C_6H_6O_7^{2-}] + [C_6H_7O_7^-] + [C_6H_8O_7] \quad (C.21)$$

From the equilibrium reaction indicating the several deprotonation steps of citric acid, the concentration of each deprotonated species can be expressed as:

$$[C_6H_8O_7] = \frac{[C_6H_7O_7^-]\cdot[H^+]}{Ka_1} \quad (C.22)$$

$$[C_6H_7O_7^-] = \frac{[C_6H_6O_7^{2-}]\cdot[H^+]}{Ka_2} \quad (C.23)$$

$$[C_6H_6O_7^{2-}] = \frac{[C_6H_5O_7^{3-}]\cdot[H^+]}{Ka_2} \quad (C.24)$$

From Eq. (C.16) and (C.17), all deprotonated species can be rewritten in terms of pH and pKa' as shown below:

$$[C_6H_8O_7] = [C_6H_7O_7^-]\cdot 10^{pKa'_1 - pH} \quad (C.25)$$

$$[C_6H_7O_7^-] = [C_6H_6O_7^{2-}]\cdot 10^{pKa'_2 - pH} \quad (C.26)$$

$$[C_6H_6O_7^{2-}] = [C_6H_5O_7^{3-}]\cdot 10^{pKa'_3 - pH} \quad (C.27)$$

where

$$pKa'_1 = pKa_1 - \frac{AI^{0.5}}{(1+I^{0.5})} + 0.1I \qquad (C.28)$$

$$pKa'_2 = pKa_2 - \frac{3AI^{0.5}}{(1+I^{0.5})} + 0.3I \qquad (C.29)$$

$$pKa'_3 = pKa_3 - \frac{5AI^{0.5}}{(1+I^{0.5})} + 0.5I \qquad (C.30)$$

Substituting Eq. (C.25) - (C.27) in Eq. (C.21) and rearranging:

$$Citricacid_{Total} = \left[C_6H_5O_7^{3-}\right]\left(1 + 10^{pKa'_3 - pH} + 10^{pKa'_3 + pKa'_2 - 2pH} + 10^{pKa'_3 + pKa'_2 + pKa'_1 - 3pH}\right) \qquad (C.31)$$

Defining:

$$A = (1 + 10^{pKa'_3 - pH} + 10^{pKa'_3 + pKa'_2 - 2pH} + 10^{pKa'_3 + pKa'_2 + pKa'_1 - 3pH}) \qquad (C.32)$$

Substituting Eq. (C.32) in Eq. (C.31), Eq. (C.31) becomes:

$$\left[C_6H_5O_7^{3-}\right] = \frac{Citricacid_{Total}}{A} \qquad (C.33)$$

Therefore, the fraction of all deprotonated species can be calculated from the following equation:

$$\text{Fraction of } \left[C_6H_5O_7^{3-}\right] \text{ species} = \frac{\left[C_6H_5O_7^{3-}\right]}{Citricacid_{Total}} = \frac{1}{A} \qquad (C.34)$$

Fraction of $\left[C_6H_6O_7^{2-}\right]$ species $= \dfrac{10^{pKa'_3 - pH}}{A}$ (C.35)

Fraction of $\left[C_6H_7O_7^{-}\right]$ species $= \dfrac{10^{pKa'_3 + pKa'_2 - 2pH}}{A}$ (C.35)

Fraction of $\left[C_6H_8O_7\right]$ species $= \dfrac{10^{pKa'_3 + pKa'_2 + pKa'_1 - 3pH}}{A}$ (C.36)

Substituting the values of pKa'_1 to pKa'_3 from Eq. (C.28) – (C.30) in Eq. (C.34) – (C.36), the fraction of all deprotonated species of citric acid is subsequently attained.

Appendix D Experimental Data

1. The Initial Rates of the Dissolution Reaction of Analcime

Table D.1 The initial rates of Si, Al and Na for each experiment

No	Analcime Size	Acid	Conc.	Initial Rate x 10^3 (mole/g/hr)		
				Si	Al	Na
1	0.71-1.18	Citric acid	0.1	0.53	0.20	0.23
2	0.212-0.300	Citric acid	0.1	0.62	0.60	0.56
3	0.150-0.180	Citric acid	0.1	1.35	1.00	1.43
4	0.045-0.075	Citric acid	0.1	4.95	3.34	3.18
5	0.71-1.18	HCl	0.047	0.15	0.11	0.18
6	0.71-1.18	HCl	0.1	0.23	0.16	0.05
7	0.71-1.18	HCl	0.2	0.69	0.44	0.71

<u>Note</u>: Experiment 1 was performed in a batch reactor with 2 g of analcime and 500 dm^3 of citric acid

Experiment 2-4 were performed in a batch reactor with 1 g of analcime and 150 dm^3 of citric acid

Experiment 5-7 were performed in vials

2. Size Distribution of Analcime Particles as a Function of Time

Table D.2 The size distribution of analcime (0.045-0.075 mm) before the reaction

Size of Particle (mm)	Number of Particle (%)		
	Dry	Wet (imediately)	Wet (24hr)
0-0.01	35.2	27.1	2.6
0.01-0.02	23.9	14.6	0.0
0.02-0.03	15.5	22.9	30.8
0.03-0.04	14.1	25.0	41.0
0.04-0.05	8.5	10.4	20.5
0.05-0.06	2.8	0.0	5.1

Table D.3 The size distribution of analcime (0.045-0.075 mm) after the dissolution reaction in 3M citric acid (series 1)

Size of Particle (mm)	Number of Particle (%)		
	2min	9min	15min
0-0.01	61.8	51.7	54.0
0.01-0.02	14.7	21.7	23.3
0.02-0.03	12.5	14.2	13.6
0.03-0.04	7.4	9.2	6.3
0.04-0.05	2.2	3.3	1.7
0.05-0.06	1.5	0.0	1.1

Table D.4 The size distribution of analcime (0.045-0.075 mm) after the dissolution reaction in 3M citric acid (series 2)

Size of Particle (mm)	Number of Particle (%)		
	2min	9min	15min
0-0.01	65.2	63.6	46.4
0.01-0.02	21.3	22.6	26.3
0.02-0.03	7.9	7.2	10.3
0.03-0.04	4.9	4.6	12.4
0.04-0.05	0.6	1.5	4.6
0.05-0.06	0.0	0.5	0.0

Table D.5 The size distribution of analcime (0.045-0.075 mm) after the dissolution reaction in 0.1M HCl (series 1)

Size of Particle (mm)	Number of Particle (%)					
	2min	9min	15min	30min	45min	60min
0-0.01	69.9	77.6	72.5	86.4	85.7	84
0.01-0.02	16.4	9.2	5.0	9.9	11.1	4
0.02-0.03	8.2	6.6	12.5	1.2	1.6	8
0.03-0.04	2.7	2.6	10.0	1.2	1.6	4
0.04-0.05	1.4	2.6	0.0	1.2	0.0	0
0.05-0.06	1.4	1.3	0.0	0.0	0.0	0

Table D.6 The size distribution of analcime (0.045-0.075 mm) after the dissolution reaction in 0.1M HCl (series 2)

Size of Particle (mm)	Number of Particle (%)					
	2min	9min	15min	30min	45min	60min
0-0.01	14.3	27.6	25.0	13.9	38.6	34.5
0.01-0.02	7.1	19.0	12.5	19.4	18.2	14.3
0.02-0.03	23.8	22.4	39.6	19.4	18.2	21.4
0.03-0.04	38.1	13.8	10.4	27.8	11.4	15.5
0.04-0.05	7.1	15.5	12.5	16.7	11.4	13.1
0.05-0.06	9.5	1.7	0.0	2.8	2.3	1.2

Table D.7 The size distribution of analcime (0.71-1.18 mm) before the reaction

Size of Particle (mm)	Number of Particle (%)		
	Dry	Wet (imediately)	Wet (24hr)
0-0.1	46.7	28.6	26.1
0.1-0.2	0.0	0.0	0.0
0.2-0.3	0.0	0.0	0.0
0.3-0.4	0.0	0.0	0.0
0.4-0.5	0.0	7.1	0.0
0.5-0.6	13.3	21.4	4.3
0.6-0.7	20.0	14.3	4.3
0.7-0.8	6.7	0.0	13.0
0.8-0.9	13.3	7.1	4.3
0.9-1.0	0.0	7.1	4.3
1.0-1.1	0.0	14.3	13.0
1.1-1.2	0.0	0.0	8.7
1.2-1.3	0.0	0.0	8.7

Table D.7 (Cont.)

Size of Particle (mm)	Number of Particle (%)		
	Dry	Wet (imediately)	Wet (24hr)
1.3-1.4	0.0	0.0	4.3
1.4-1.5	0.0	0.0	0.0
1.5-1.6	0.0	0.0	0.0
1.6-1.7	0.0	0.0	8.7

Table D.8 The size distribution of analcime (0.71-1.18 mm) after the dissolution reaction in 3M citric acid (series 1)

Size of Particle (mm)	Number of Particle (%)		
	2min	9min	15min
0-0.1	61.5	89.2	93.1
0.1-0.2	1.5	1.2	0.0
0.2-0.3	0.0	0.0	0.0
0.3-0.4	3.1	0.6	0.0
0.4-0.5	1.5	1.2	0.0
0.5-0.6	6.2	1.2	1.4
0.6-0.7	9.2	4.2	1.4
0.7-0.8	10.8	0.6	1.4
0.8-0.9	4.6	0.6	2.8
0.9-1.0	1.5	0.6	0.0
1.0-1.1	0.0	0.6	0.0
1.1-1.2	0.0	0.0	0.0
1.2-1.3	0.0	0.0	0.0
1.3-1.4	0.0	0.0	0.0

Table D.9 The size distribution of analcime (0.71-1.18 mm) after the dissolution reaction in 3M citric acid (series 2)

Size of Particle (mm)	Number of Particle (%)		
	2min	9min	15min
0-0.1	72.9	75.7	89.3
0.1-0.2	0.0	0.0	0.0
0.2-0.3	1.2	0.0	0.0
0.3-0.4	1.2	0.0	0.0
0.4-0.5	5.9	1.4	1.3
0.5-0.6	9.4	5.7	0.0
0.6-0.7	1.2	11.4	5.3
0.7-0.8	4.7	4.3	2.7
0.8-0.9	2.4	0.0	1.3
0.9-1.0	0.0	1.4	0.0
1.0-1.1	1.2	0.0	0.0
1.1-1.2	0.0	0.0	0.0
1.2-1.3	0.0	0.0	0.0
1.3-1.4	0.0	0.0	0.0

Table D.10 The size distribution of analcime (0.71-1.18 mm) after the dissolution reaction in 0.1M HCl (series 1)

Size of Particle (mm)	Number of Particle (%)						
	2min	9min	15min	60min	180min	240min	24hr
0-0.1	0.0	43.5	81.1	93.2	93.9	89.3	98.9
0.1-0.2	0.0	0.0	0.0	0.0	0.9	1.0	0.0
0.2-0.3	0.0	0.0	0.0	0.0	0.0	1.0	0.0
0.3-0.4	10.0	4.3	0.0	0.0	0.0	1.9	0.0

Table D.10 (Cont.)

Size of Particle (mm)	Number of Particle (%)						
	2min	9min	15min	60min	180min	240min	24hr
0.4-0.5	0.0	13.0	2.7	0.0	1.8	2.9	0.0
0.5-0.6	30.0	8.7	2.7	2.3	0.9	1.0	1.1
0.6-0.7	40.0	13.0	10.8	2.3	1.8	1.9	0.0
0.7-0.8	0.0	13.0	2.7	2.3	0.0	0.0	0.0
0.8-0.9	10.0	4.3	0.0	0.0	0.0	1.0	0.0
0.9-1.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
1.0-1.1	10.0	0.0	0.0	0.0	0.0	0.0	0.0
1.1-1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.2-1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.3-1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.4-1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.5-1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.6-1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.11 The size distribution of analcime (0.71-1.18 mm) after the dissolution reaction in 0.1M HCl (series 2)

Size of Particle (mm)	Number of Particle (%)					
	2min	9min	15min	60min	180min	240min
0-0.1	38.9	52.2	65.1	91.9	99.0	98.4
0.1-0.2	0.0	0.0	0.0	0.0	0.0	0.8
0.2-0.3	5.6	0.0	0.0	0.0	0.0	0.0
0.3-0.4	11.1	0.0	4.7	0.0	0.0	0.0
0.4-0.5	11.1	4.3	14.0	0.0	0.0	0.0
0.5-0.6	22.2	21.7	9.3	2.7	0.0	0.8

Table D.11 (Cont.)

Size of Particle (mm)	Number of Particle (%)					
	2min	9min	15min	60min	180min	240min
0.6-0.7	5.6	8.7	4.7	5.4	0.0	0.0
0.7-0.8	5.6	4.3	2.3	0.0	1.0	0.0
0.8-0.9	0.0	8.7	0.0	0.0	0.0	0.0
0.9-1.0	0.0	0.0	0.0	0.0	0.0	0.0
1.0-1.1	0.0	0.0	0.0	0.0	0.0	0.0
1.1-1.2	0.0	0.0	0.0	0.0	0.0	0.0
1.2-1.3	0.0	0.0	0.0	0.0	0.0	0.0
1.3-1.4	0.0	0.0	0.0	0.0	0.0	0.0
1.4-1.5	0.0	0.0	0.0	0.0	0.0	0.0
1.5-1.6	0.0	0.0	0.0	0.0	0.0	0.0
1.6-1.7	0.0	0.0	0.0	0.0	0.0	0.0

Table D.12 The size distribution of analcime (0.71-1.18 mm) after the dissolution reaction in 0.2 HCl (series 1)

Size of Particle (mm)	Number of Particle (%)						
	2min	9min	15min	60min	120min	240min	24hr
0-0.1	23.5	0.0	40.0	37.7	80.4	75.0	53.3
0.1-0.2	7.8	0.0	17.1	22.6	8.9	13.3	15.6
0.2-0.3	3.9	0.0	11.4	3.8	1.8	3.3	15.6
0.3-0.4	11.8	0.0	0.0	1.9	0.0	3.3	6.7
0.4-0.5	27.5	3.6	2.9	5.7	1.8	1.7	0.0
0.5-0.6	11.8	17.9	0.0	0.0	1.8	0.0	0.0
0.6-0.7	7.8	3.6	0.0	0.0	0.0	0.0	2.2
0.7-0.8	3.9	0.0	0.0	0.0	1.8	0.0	2.2

Table D.12 (Cont.)

Size of Particle (mm)	Number of Particle (%)						
	2min	9min	15min	60min	120min	240min	24hr
0.8-0.9	2.0	7.1	0.0	0.0	0.0	0.0	0.0
0.9-1.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0
1.0-2.0	0.0	0.0	8.6	0.0	1.8	0.0	2.2
2.0-3.0	0.0	46.4	20.0	15.1	1.8	1.7	0.0
3.0-4.0	0.0	17.9	0.0	11.3	0.0	1.7	2.2
4.0-5.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0

Table D.13 The size distribution of analcime (0.71-1.18 mm) after the dissolution reaction in 0.2 HCl (series 2)

Size of Particle (mm)	Number of Particle (%)						
	2min	9min	15min	60min	120min	240min	24hr
0-0.1	33.3	39.1	81.1	94.0	93.5	98.5	99.2
0.1-0.2	0.0	2.2	0.0	0.0	0.0	0.7	0.8
0.2-0.3	0.0	0.0	0.0	1.0	0.0	0.0	0.0
0.3-0.4	8.9	6.5	2.5	2.0	0.8	0.0	0.0
0.4-0.5	6.7	17.4	7.4	1.0	1.6	0.7	0.0
0.5-0.6	28.9	17.4	4.9	1.0	2.4	0.0	0.0
0.6-0.7	11.1	6.5	1.6	1.0	0.8	0.0	0.0
0.7-0.8	8.9	6.5	1.6	0.0	0.8	0.0	0.0
0.8-0.9	2.2	2.2	0.8	0.0	0.0	0.0	0.0
0.9-1.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0
1.0-2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2.0-3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table D.13 (Cont.)

Size of Particle (mm)	Number of Particle (%)						
	2min	9min	15min	60min	120min	240min	24hr
3.0-4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.0-5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

3. Mass Balance for Experiment Performed in Vials

Table D.14 Mass balance for the experiment of analcime (0.045-0.075 mm) with 3M citric acid

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	1	0.094	12.551	0.063	10.314	12.645	10.377	2.268
0.15	1	0.099	11.907	0.044	9.901	12.006	9.945	2.061
0.25	1	0.092	11.852	0.039	10.268	11.9442	10.308	1.637
0.03	2	0.096	11.897	0.061	9.786	11.9927	9.846	2.146
0.15	2	0.092	11.872	0.047	10.555	11.9636	10.603	1.361
0.25	2	0.093	11.720	0.042	10.106	11.8132	10.149	1.665

Table D.15 Mass balance for the experiment of analcime (0.045-0.075 mm) with 0.047M HCl

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	1	0.091	9.763	0.085	8.650	9.854	8.735	1.119
0.15	1	0.094	9.750	0.083	8.477	9.844	8.561	1.283
0.25	1	0.092	9.747	0.081	8.442	9.838	8.523	1.316
0.03	2	0.095	9.761	0.087	9.246	9.856	9.333	0.523
0.13	2	0.093	9.765	0.084	8.883	9.858	8.967	0.892
0.25	2	0.094	9.752	0.085	8.598	9.845	8.684	1.162

Table D.16 Mass balance for the experiment of analcime (0.045-0.075 mm) with 0.1M HCl

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass lost
0.03	1	0.094	9.857	0.418	8.178	9.951	8.595	1.356
0.15	1	0.091	9.842	0.414	8.355	9.933	8.769	1.164
0.25	1	0.092	9.880	0.079	8.700	9.973	8.779	1.194
0.50	1	0.095	10.102	0.073	8.521	10.197	8.594	1.603
0.75	1	0.096	10.075	0.069	8.432	10.171	8.501	1.670
1.00	1	0.095	10.231	0.061	8.128	10.325	8.188	2.137
0.03	2	0.092	9.809	0.087	9.054	9.901	9.141	0.760
0.15	2	0.092	9.758	0.081	9.205	9.850	9.286	0.564
0.25	2	0.092	9.768	0.080	8.218	9.860	8.298	1.563
0.50	2	0.095	9.814	0.074	8.777	9.909	8.851	1.058
0.75	2	0.092	9.779	0.066	8.086	9.871	8.152	1.719

Table D.16 (Cont.)

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass lost
1.00	2	0.094	9.754	0.066	8.745	9.847	8.811	1.036

Table D.17 Mass balance for the experiment of analcime (0.71-1.18 mm) with 3M citric acid

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	1	0.100	11.839	0.099	9.175	11.939	9.273	2.666
0.15	1	0.093	12.064	0.091	9.226	12.156	9.317	2.840
0.25	1	0.095	12.071	0.092	9.259	12.166	9.350	2.816
0.03	2	0.098	12.539	0.099	9.788	12.637	9.886	2.751
0.15	2	0.094	12.524	0.093	9.657	12.618	9.750	2.87
0.25	2	0.099	12.514	0.098	9.946	12.613	10.044	2.569

Table D.18 Mass balance for the experiment of analcime (0.71-1.18 mm) with 0.047M HCl

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	1	0.100	9.866	0.100	8.123	9.967	8.223	1.743
0.15	1	0.098	10.249	0.094	8.537	10.347	8.631	1.716
0.25	1	0.095	10.228	0.095	8.824	10.324	8.919	1.405

Table D.18 (Cont.)

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	2	0.092	9.768	0.091	8.331	9.860	8.422	1.438
0.15	2	0.098	9.786	0.096	7.737	9.883	7.832	2.051
0.25	2	0.092	9.749	0.090	8.201	9.841	8.291	1.551

Table D.19 Mass balance for the experiment of analcime (0.71-1.18 mm) with 0.1M HCl

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	1	0.092	10.318	0.090	8.615	10.409	8.706	1.704
0.15	1	0.098	10.269	0.091	8.675	10.367	8.766	1.601
0.25	1	0.092	10.273	0.092	8.551	10.365	8.643	1.722
1.00	1	0.094	9.808	0.085	8.724	9.901	8.808	1.093
2.00	1	0.096	9.782	0.082	8.719	9.877	8.800	1.077
3.00	1	0.091	9.802	0.075	8.447	9.893	8.523	1.370
4.00	1	0.104	9.779	0.074	8.421	9.883	8.495	1.388
24.00	1	0.099	10.298	0.026	7.996	10.397	8.022	2.375
18.00	1	0.092	9.792	0.043	8.127	9.884	8.170	1.714
0.03	2	0.096	9.785	0.095	8.479	9.881	8.574	1.307
0.15	2	0.094	9.708	0.092	8.465	9.802	8.556	1.246
0.25	2	0.095	9.713	0.094	8.857	9.808	8.951	0.857
1.00	2	0.098	9.794	0.092	8.288	9.892	8.380	1.512
2.00	2	0.095	9.800	0.083	8.306	9.894	8.389	1.505

Table D.19 (Cont.)

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
3.00	2	0.093	9.768	0.076	8.547	9.861	8.623	1.238
4.00	2	0.093	9.762	0.068	9.037	9.855	9.105	0.749

Table D.20 Mass balance for the experiment of analcime (0.71-1.18 mm) with 0.2M HCl

Time (hr)	#	Initial wt. (g)		Final wt. (g)		Total wt. (g)		
		Solid	Solution	Solid	Filtrate	Initial	Final	Mass Lost
0.03	1	0.101	9.836	0.099	8.254	9.938	8.353	1.585
0.15	1	0.105	9.740	0.104	8.578	9.845	8.682	1.163
0.25	1	0.092	9.739	0.090	8.382	9.831	8.472	1.359
1.00	1	0.095	9.736	0.085	8.426	9.831	8.511	1.320
2.00	1	0.102	9.757	0.080	8.516	9.859	8.596	1.263
4.00	1	0.100	9.746	0.062	8.410	9.846	8.472	1.374
24.00	1	0.092	9.753	0.014	8.112	9.845	8.125	1.719
0.03	2	0.094	9.748	0.094	8.977	9.842	9.071	0.771
0.15	2	0.099	9.726	0.097	8.734	9.825	8.831	0.994
0.25	2	0.105	9.802	0.103	8.582	9.907	8.684	1.222
1.00	2	0.092	9.809	0.086	8.586	9.901	8.672	1.229
2.00	2	0.093	9.769	0.071	8.606	9.862	8.677	1.185
4.00	2	0.097	9.764	0.069	8.377	9.861	8.446	1.415
24.00	2	0.099	9.779	0.015	8.356	9.877	8.371	1.506

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